MICROBIOLOGICAL STUDIES ON LIFE SUPPORT SUBSYSTEMS FOR MANNED SPACE FLIGHT

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ABSTRACT

Currently under investigation at the Langley Research Center in Hampton, Virginia, is a research test chamber to study and test critical life support subsystems for long-duration space missions. This system is designed to support four men for 90 days without resupply. Critical life support subsystems include the recovery of water from urine, waste management, and personal hygiene. Microbiological studies in support of the development and testing of these subsystems are reported. Special emphasis will be placed on the microbiological problems associated with the recovery of water from urine using a wick evaporator system. Such factors as system sterilization, antimicrobial treatment procedures, and laboratory methodology to meet biological standards are discussed. Laboratory investigations associated with other life support subsystems are also presented. Microbiological results obtained during closed-door testing of the integrated life support system test chamber are reviewed.

INTRODUCTION

During the past 5 years the National Space Program has, by the process of evolution, developed systems for successfully sustaining one or two individuals in closed systems for space flights of short and intermediate periods of time.

The next decade, however, will require systems capable of supporting larger space crews of four or more for periods of long duration. Progress is being made in many areas toward the goal of long-duration, manned space flight and a considerable portion of this effort is focused on the total space cabin environment including research and development on life support subsystems.

Many of the anticipated microbiological problems of long-term space flight are amenable to examination through the use of environmental test chambers specifically designed and constructed for human occupancy. The Integrated Life Support System (ILSS) at the Langley Research Center, National Aeronautics and Space Administration, Hampton, Virginia, is an example of such an installation which utilizes a physical-chemical regenerative life support system to sustain a crew of four men for extended time periods. This paper summarizes the microbiological research and development program on life support subsystems associated with the ILSS and it presents the results of studies conducted during manned, closed-door testing.

LIFE SUPPORT REQUIREMENTS

Before man is able to explore the solar system, provisions must be made to serve his life needs - at the same time insuring his safe return to earth. It will be necessary to provide food, water, atmosphere control, and waste removal. It is apparent that for long-duration missions, stored supplies, if used, would require enormous weights. Near-earth missions can rely on resupply, but planetary missions cannot, and for such missions recycle systems are necessary. Another way of looking at the same problem is to consider that a 150-lb man consumes the equivalent of his weight in food, water, and oxygen in about 15 days and in only 6 months requires about a ton of these basic ingredients.

Therefore, it will be necessary to use some of man's output for developing an input. Urine appears to be one of the first wastes which will be reclaimed since it can readily be made drinkable (urine is 93 percent water). Another area which can result in conserving weight and space is to produce oxygen onboard. One way to supply a portion of oxygen is to recover it from water and/or carbon dioxide. Recovery of oxygen from water can be accomplished by electrolysis (1).

The Integrated Life Support System

The integrated life support system or ILSS is a cylindrical chamber with domed ends as shown in figure 1. The chamber has a diameter of 18 feet 2 inches and a height of 18 feet. The interior volume (4150 ft^3) is divided into two levels to accommodate the various functional requirements of the crew. An airlock chamber is attached to the external shell of the test bed at the lower level to permit access to the test bed when the chamber is at pressures less than atmospheric. Figure 2 is an exterior view of the ILSS test chamber.

The ILSS is designed to support four men in earth orbit with resupply on a 90-day basis. The ILSS regenerative processes are shown in figure 3. In this system, water is recovered from urine, humidity condensate, and wash water using a wick evaporator concept. Oxygen is recovered through electrolysis with the hydrogen reacting with the oxygen to generate more water. In the Bosch reaction the carbon from carbon dioxide is collected as a solid. In this system solid wastes are dried and stored.

MICROBIOLOGICAL STUDIES

Life Support Subsystems

Water management.- The ILSS water management system produces potable water from both waste water and humidity condensate by means of two identical evaporation units. Unit No. 1 processes humidity condensate and wash water; Unit No. 2 processes only urine. A bench model of the water management system which is used for investigational purposes is shown in figure 4.

Water recovery is performed by moving a heated airstream through an evaporator in which chemically treated waste water is held in a rayon wick by absorption. Saturated air is directed through a charcoal bed followed by a condenser downstream after which air is removed from the water by a centrifugal separator. Condensate from these units is delivered gas-free through a second charcoal filter and then to holding tanks for analysis.

Before presenting the results of microbiological studies with the ILSS unit, it is worthwhile at this time to discuss briefly the problem of water quality standards for long-duration, manned space missions. At the request of the NASA, the National Academy of Science through its Space Science Board delegated an ad hoc panel to examine this problem and establish water quality standards for space missions (2). In summary, the panel felt that water supplies for long-duration space flight need to be at least as wholesome and acceptable as those provided by municipalities conforming to the Public Health drinking water standards. In view of the fact that the quality of the raw water for space recovery is far different from municipal supplies and that the water will be recycled through the human system many times during space flight, the panel felt greater stringency in biological quality requirements was

needed to maintain required wholesomeness. It was considered that the goal should be essential sterility and that counts of aerobic, facultative, and anaerobic organisms would be the best indications of attainment of this condition. A maximum of 10 viable micro-organisms per ml was considered to be a realistic criterion for "essential sterility" (table I).

A number of microbiological tests have been conducted with the ILSS wick evaporator unit in which pretreatment consisted of a thorough cleaning of the unit with a 0.2-percent solution of benzalkonium chloride (BAC). Results obtained during 3- and 4-day closed-door tests of the ILSS are summarized in table II. It is apparent from these studies that the product water did not meet the recommended standards of a maximum of 10 viable micro-organisms per ml and therefore was not consumed by the crews. Total plate counts at the end of the two tests averaged around 10^6 bacteria per ml. These bacteria were identified as belonging to the Pseudomonas, Achromobacter, Alcaligenes groups which are widely distributed in nature and commonly found in water and soil (3). It is of interest that no viable bacteria were recovered from the water tap of the food management subsystem which operates at a temperature of 160° F indicating that terminal heat treatment was sufficient to kill the bacteria. However, in view of the fact that the panel recommended that the criterion of "essential sterility" apply to all parts of the recovery system beyond the initial phase separation step and not simply to the finished product water, it is apparent that terminal heat treatment of a system heavily contaminated with bacteria is not sufficient to meet the standards.

A research program is currently underway at the Langley Research Center which has the objective of meeting the recommended water quality standards. A team composed of engineers, bacteriologists, and chemists with laboratory

backup support are actively engaged in the redesign and performance testing of the ILSS bench unit. During the initial stages of this program, it was decided to follow the guidelines of the ad hoc panel which recommended heat as the sterilizing procedure and the ILSS unit has been redesigned to permit the introduction of flowing steam into the system. This procedure, coupled with heat treatment of the raw urine, has resulted in the production of water which meets the standards. Although these preliminary results are encouraging, much additional work is required before the system can meet the requirements of long-term reliability and safety.

Waste management.- The ILSS waste management consists of a spacetype feces/refuse collector, dryer, and storage units; a urine collector, liquid-gas separator, and associated support equipment. The feces/refuse collector utilizes an airstream to direct the matter into an air-permeable bag which is manually transferred to one of the two dryers in the system. The feces/refuse dryer dehydrates the contained matter by vacuum and/or heat provided by the thermal control system and vents the released water vapor overboard through a bacterial filter. Microbiological studies were made on air and surface samples. Swab samples were taken from the collecting cone of the fecal collector and the vacuum control handle; RODAC plates were used to take samples from the floor, toilet seat, wall, and the right- and left-hand fingers of the crew members using the system. Andersen sieve samplers were used to determine the number of airborne micro-organisms. During sampling of the waste management subsystem, a medium selective for the growth of Escherichia coli was used, as this micro-organism is commonly associated with fecal contamination. At no time during the training period or use of the system inside the test chamber was E. coli isolated from the air, the waste management subsystem, surrounding

surfaces (walls, floors, etc.), or from the fingers of the subjects. The fact that E. coli was not isolated is good assurance that gross fecal contamination did not occur during use of the subsystem. On the other hand, it does raise the question of the validity of using E. coli as the only indicator organism in testing such systems. Historically, E. coli has been used in certifying the quality of water from municipal systems, and its presence in such water indicates fecal contamination. The uniqueness of waste management subsystems within the constraints of closed environments for space travel forces a reexamination of sampling techniques, selection of indicator micro-organisms, and media requirements. This review is currently underway and should lead to testing procedures which are more amenable to space flight conditions.

ILSS environmental studies.- Microbiological studies of the ILSS environment were conducted during 3- and 4-day testing. Both tests were conducted with crews of four men each, alternating on an 8-hour shift basis to provide continuous occupancy for real system loading. Microbiological studies made inside the test chamber during these two tests included sampling for airborne micro-organisms and recovery of bacteria from the water management subsystem and selected surfaces. In addition, microbiological studies were conducted during use of the waste management subsystem. With the exception of crew members who used the waste management subsystem, no microbiological studies were made on personnel before, during, or after the two tests.

One of the most interesting findings which emerged from the two tests was the daily periodicity in the number of airborne bacteria collected inside the chamber. In the 3-day test, high counts were recorded at 2200 hours and low values at 0600 hours (fig. 5). In contrast, the 4-day test results showed high counts at 1400 hours and low values at 2200 hours (fig. 6).

The reasons for a daily periodicity in the counts and the marked difference between the two tests when the high and low values appeared are not readily apparent. At first glance it appears that a correlation might exist between these counts and personnel activity inside the chamber. However, all counts were made approximately 1 hour before termination of the shift and the degree of activity at this time is about the same for all shifts. A more reasonable explanation might center around the shedding of bacteria by individuals inside the chamber. In support of this approach is the fact that some individuals shed large numbers of micro-organisms into the atmosphere. Quantitative studies indicate that some persons may shed as many as 60,000 viable particles per minute (4). Thus, if such a "shedder" were present in the chamber, "clouds" of microbial aerosols would be generated as he moved about in the chamber. Collection of such aerosols would then result in proportionately higher levels of airborne viable particles. Further, this concept would receive additional support if one of the persons responsible for taking samples for microbiological analysis were a heavy "shedder." In the normal course of sampling, these persons are in close proximity to the air sampler when it is operating, and hence, clouds of aerosols containing large numbers of micro-organisms would be collected. Finally, a check of the personnel inside the chamber during the two tests indicated that only one person was present in both shifts when high counts were recorded. In addition, this person was not responsible for taking microbial samples. If this one person were a heavy "shedder," the question of whether his presence in the chamber would contribute to the high counts remains unanswered at this time. Certainly, the testing of candidates for chamber tests along the lines described by Riemensnider (4)

would aid in determining the role of "shedders" in the numbers and types of micro-organisms recovered from the air of closed environments.

Additional microbiological studies showed no consistent patterns in the numbers and types of micro-organisms recovered from selected surfaces of the chamber during the two tests. However, a buildup in bacteria recovered from the urine receptacle was observed during the 3-day test. This occurred toward the end of the test, and could possibly indicate carelessness on the part of the user to actuate the mechanism which flushes the receptacle with a solution of BAC.

CONCLUSIONS

It is apparent from the limited studies summarized in this paper that considerable effort must be expended in microbiological investigations before long-duration, manned space flights are attempted. By necessity these studies must not only include the development of safe and reliable life support subsystems, but they should consider the effect of these environments on man and the associated microbiological problems. Although microbiological investigations in support of this entire program are now underway at the NASA and other institutions, additional research is needed. It should also be pointed out that such programs are not only important to our space program but such information could very well lead to a better understanding of the health and welfare of man on earth.

REFERENCES

1. Heitchue, R. D.: Space Age Fundamentals. Douglas Report SM-47656, Douglas Aircraft Co., Inc., 1964, p. 52.
2. Water Quality Standards for Long-Duration Manned Space Missions. Report of an ad hoc panel. National Academy of Science, Space Science Board, September, 1967.
3. Breed, Robert S.; Murray, E. G. D.; and Smith, N. R.: Bergey's Manual of Determinative Bacteriology. The Williams and Wilkins Company, Baltimore, 1957.
4. Riemensnider, Dick K.: Quantitiative Aspects of Shedding of Micro-organisms by Humans. NASA SP-108, 1965.

TABLE I.- RECOMMENDED BIOLOGICAL STANDARDS OF DRINKING WATER FOR SPACE USE*

- ESSENTIAL STERILITY

- MAXIMUM OF 10 VIABLE MICROORGANISMS PER MILLILITER CONSIDERED A REALISTIC CRITERION OF "ESSENTIAL STERILITY"

- CRITERION APPLIED TO ALL PARTS OF SYSTEM BEYOND INITIAL PHASE SEPARATION, NOT SIMPLY TO FINISHED PRODUCT WATER

*FROM NATIONAL ACADEMY OF SCIENCE, SPACE SCIENCE BOARD AD HOC PANEL REPORT ON WATER QUALITY STANDARDS FOR LONG-DURATION MANNED SPACE MISSIONS

TABLE II.- NUMBER OF BACTERIA RECOVERED FROM THE WATER MANAGEMENT SYSTEM AND FOOD PROCESSING MODULE

	RESULTS, DAY OF TEST			
	3-DAY TEST		4-DAY TEST	
WATER MANAGEMENT SYSTEM	1	3	1	4
PROCESSED URINE	9×10^{2}*	4×10^{5}	1×10^{6}	USD**
PROCESSED HUMIDITY CONDENSATE AND WASH WATER	2×10^{3}	2×10^{5}	3×10^{5}	1×10^{6}
FOOD PROCESSING MODULE				
HOT WATER TAP	1×10^{2}	0	0	0
COLD WATER TAP	2×10^{2}	8×10^{2}	0	0

*BACTERIA PER ml. IDENTIFIED AS BELONGING TO: PSEUDOMONAS SPP., ACHROMOBACTER, SPP, ALCALIGENES SPP.

**UNIT SHUT DOWN

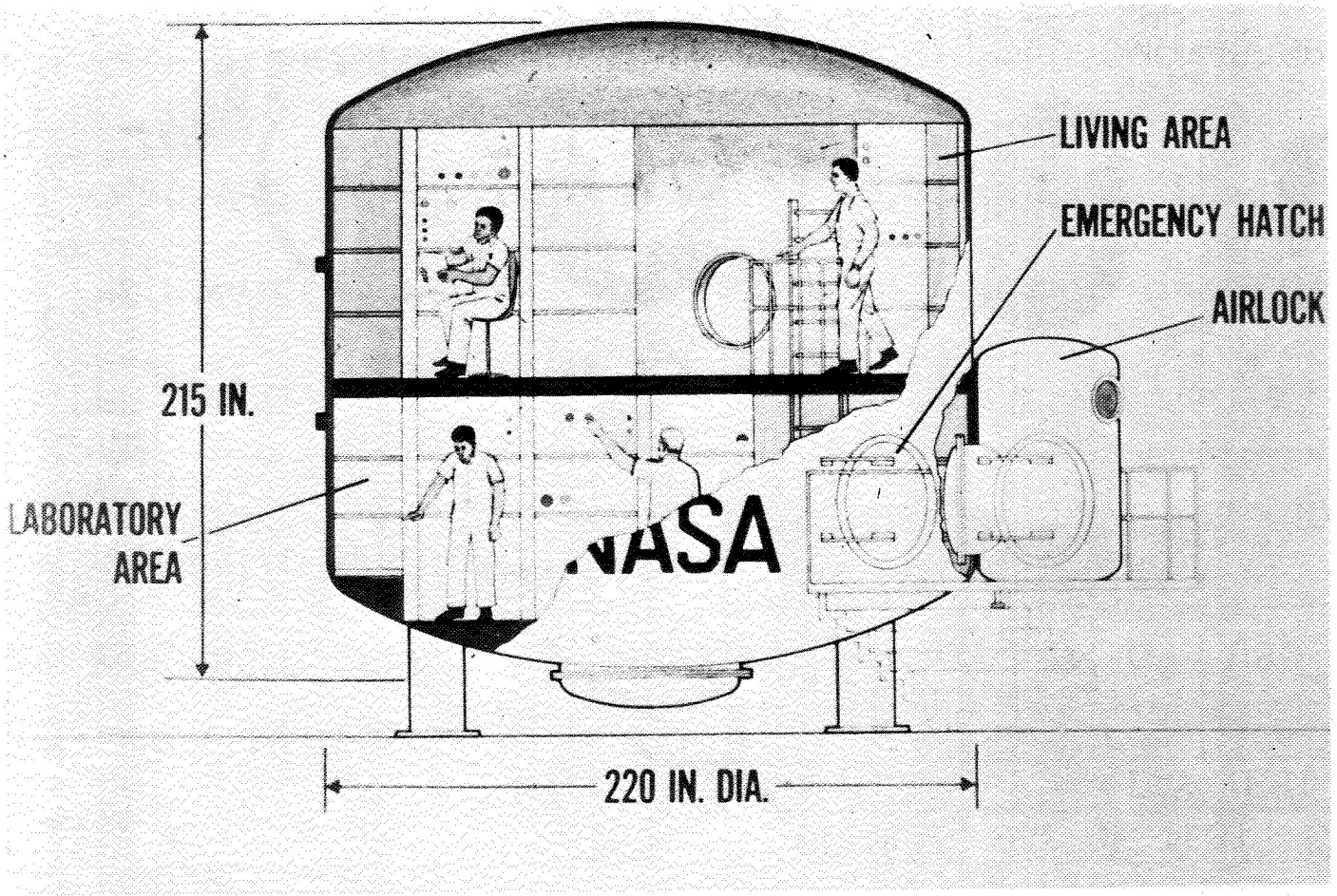

Figure 1.- Cross-section view of the Integrated Life Support System (ILSS) test chamber.

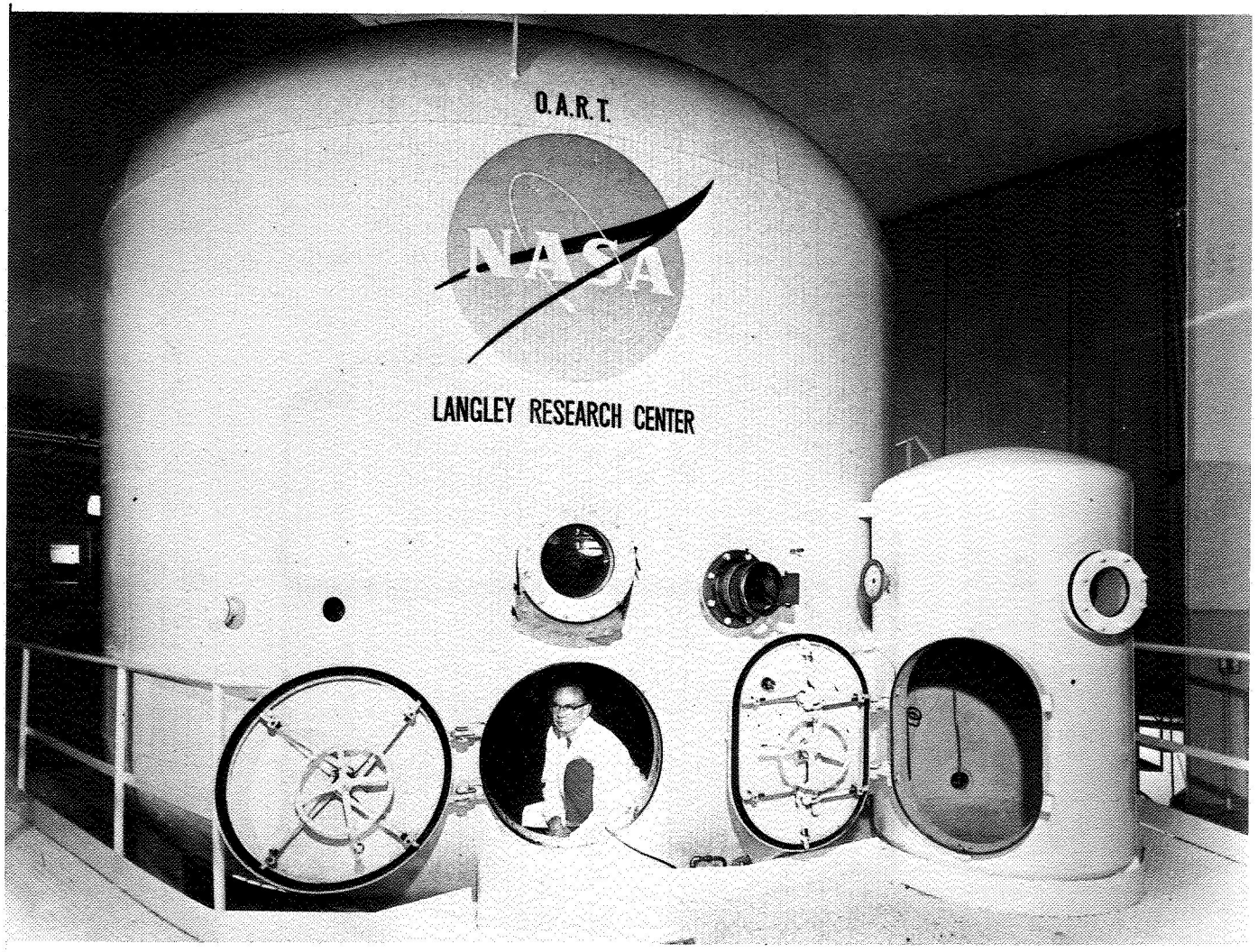

Figure 2.- Exterior view of the Integrated Life Support System (ILSS) test chamber.

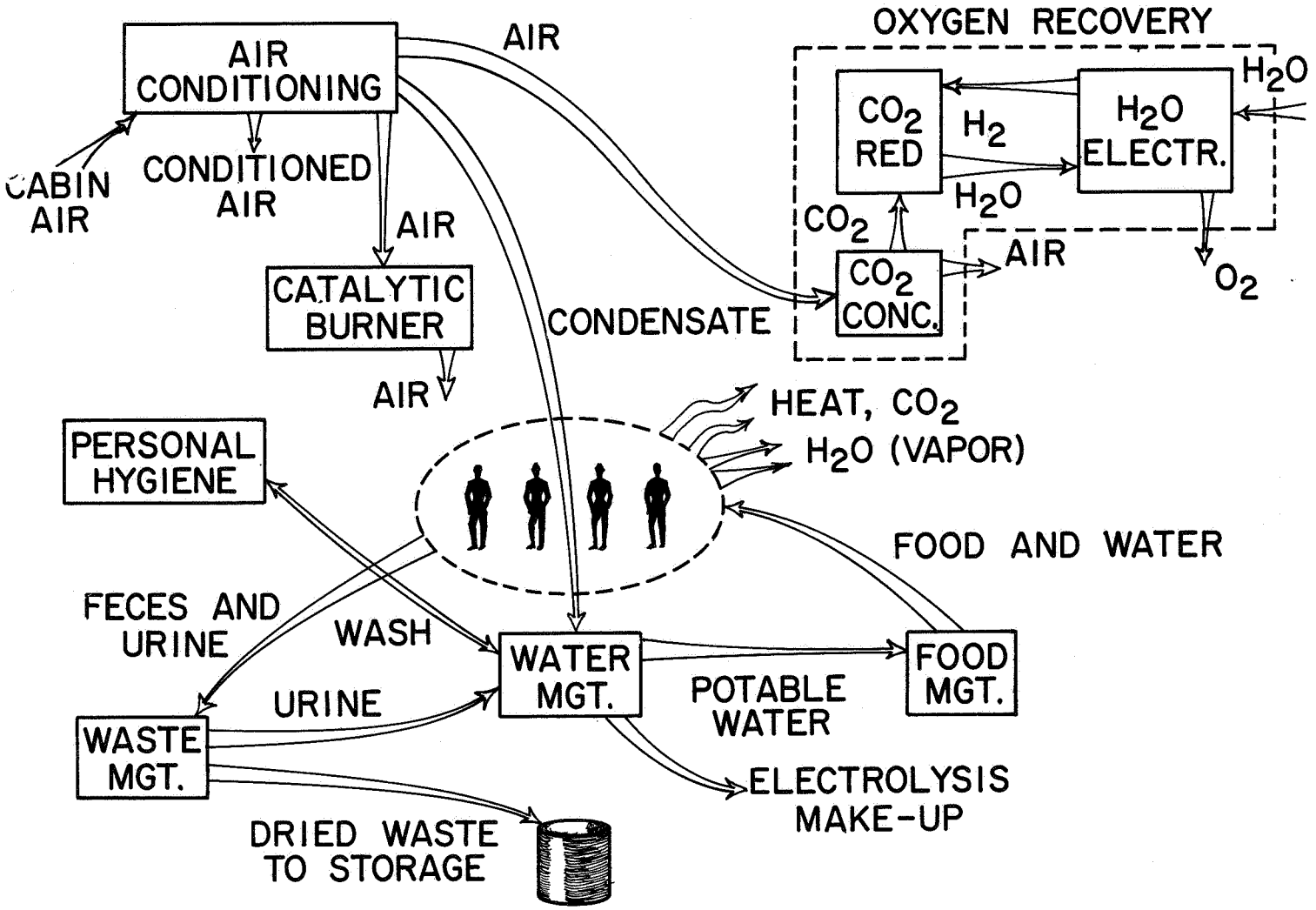

Figure 3.- Flow diagram of the Integrated Life Support System (ILSS) regenerative processes.

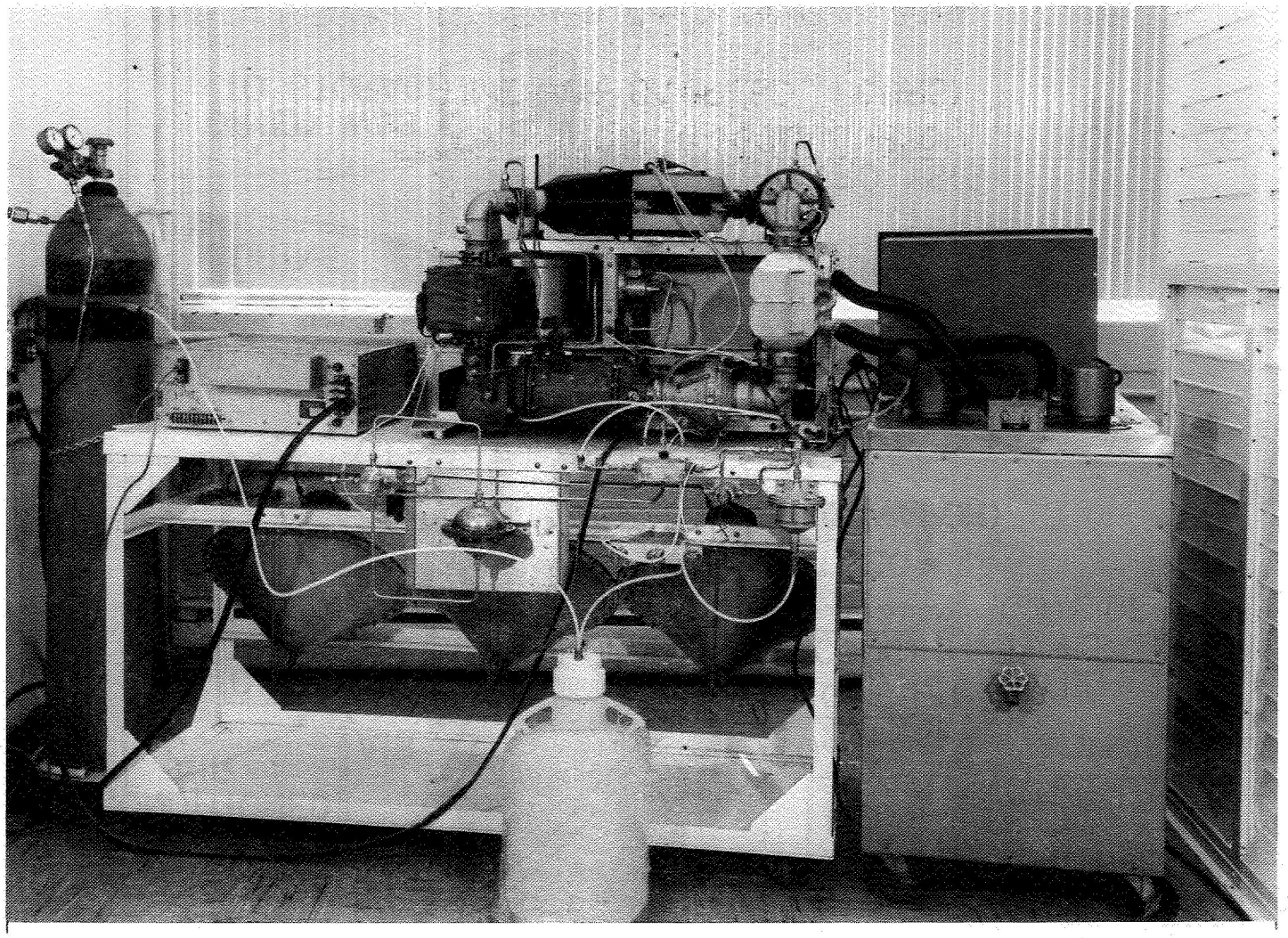

Figure 4.- ILSS water management subsystem; bench model.

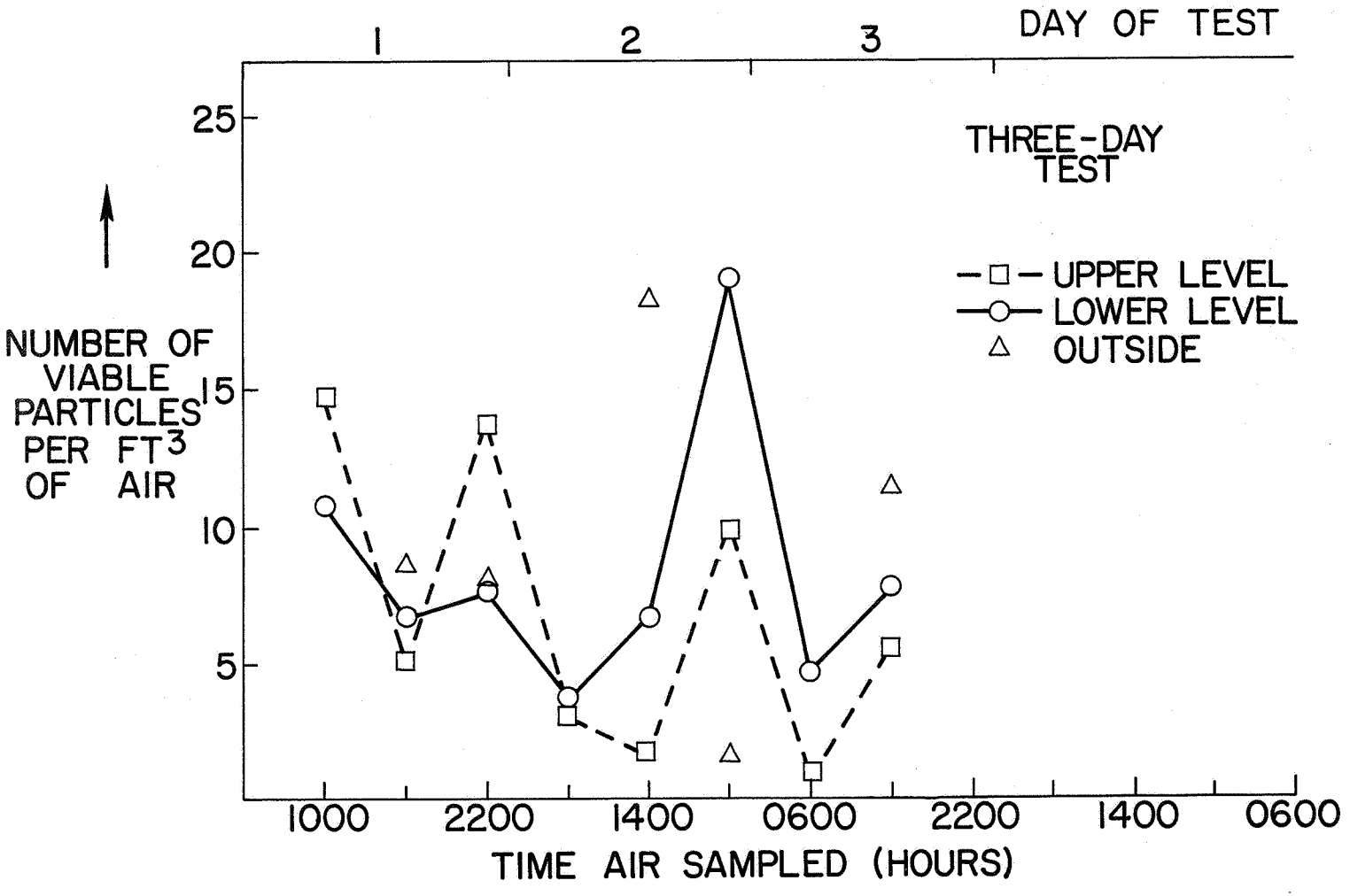

Figure 5.- Results of air sampling studies conducted during 3-day test.

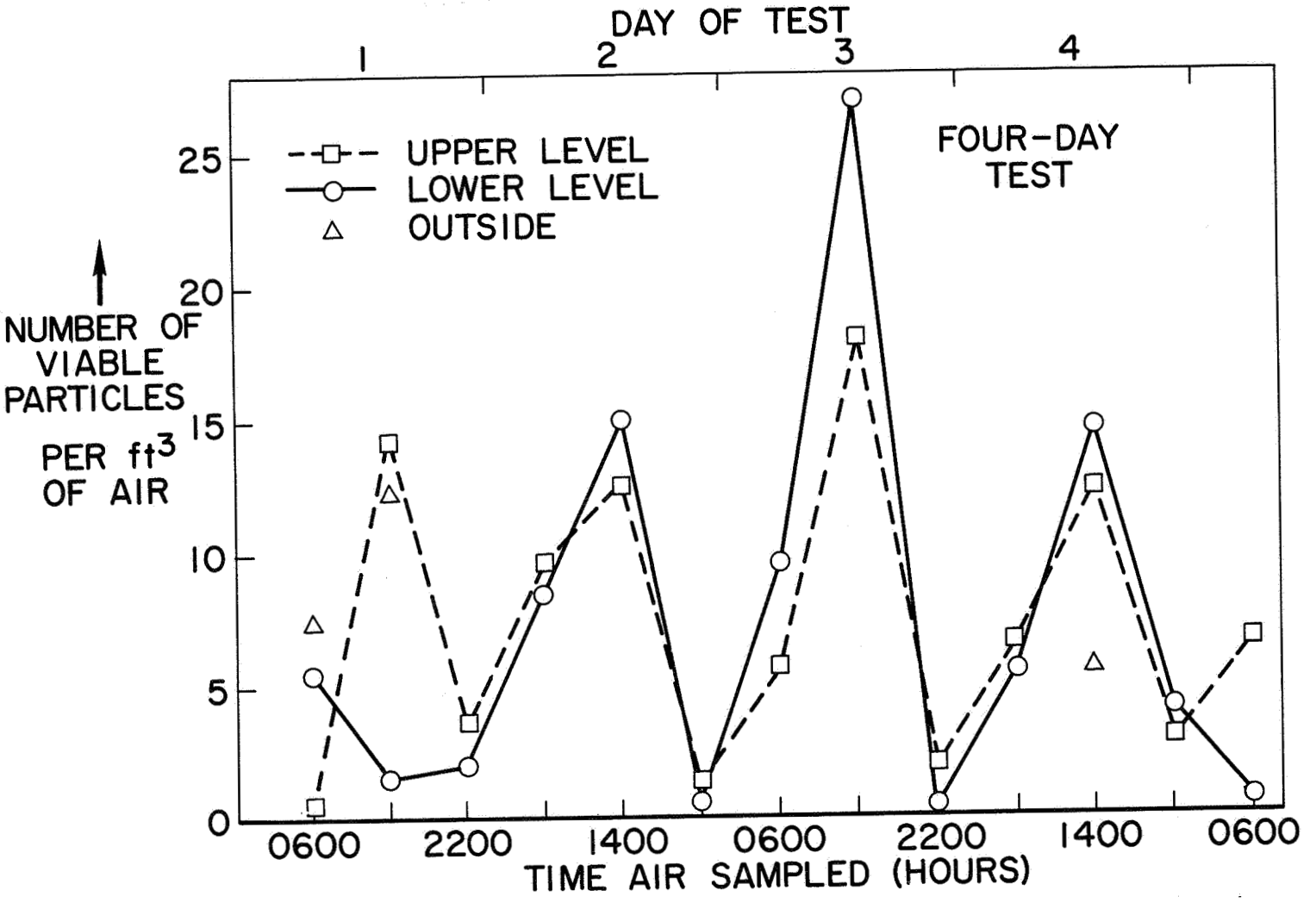

Figure 6.- Results of air sampling studies conducted during 4-day test.